A CIRCUIT METHOD AND SYSTEM FOR TRANSMITTING INFORMATION

FIELD OF THE INVENTION

[001] The present invention relates generally to the field of communications. More specifically, the present invention relates to the transmission of data through either a wireless or wired data link, at carrier frequencies ranging from low RF ranges to high microwave or optical ranges.

BACKGROUND

[002] Since the development of crude communication systems based on electrical signals, the world's appetite for more and more advanced forms of communication has continually increased. From wired cable networks over which operators would exchange messages using Morse-Code, to the broadband wireless networks of today, whenever technology has provided a means by which to communicate more information, people have found a use for that means.

[003] Modern communication networks are best characterized by features such as high bandwidth/data-rate, complex communication protocols, various transmission medium, and various access means. Fiber optic networks span much of the world's surface, acting as long-haul networks for carrying tremendous amounts of data between distant points in the world. Cable and other wire-based networks supplement coverage provided by fiber optic networks, where fiber has not yet been laid, and

are still used as part of local area networks ("LAN"), for carrying data between points relatively close to one another. In addition to wire-based networks, wireless networks such as cellular networks (e.g. 2G, 3G, CDMA, WCDMA, WiFi, etc.) may be used to supplement coverage for devices (cell phone, wireless IP phone, wireless internet appliance, etc.) not connected to a fixed network connection. Wireless networks may act as complete local loop networks and may provide a complete wireless solution, where a communication device in an area may transmit and receive data from another device entirely across the wireless network.

[004] With the proliferation of communication networks and the world's growing reliance upon them, proper performance is crucial. High data rates and stable communication parameters at low power consumption levels are highly desirable for communication devices. However, degradation of signal-to-noise ratio ("SNR") as well as Bit energy to noise ratio ("Eb/No") and interference ratio such as Carrier to-Interference ("C/I") ratio occur to a signal carried along a transmission medium (e.g. coax, unshielded conductor, wave guide, open air or even optical fiber or RF over fiber). This degradation and interferences may occur in TDMA, CSMA, CDMA, EVDO, WCDMA and WiFi networks respectively. Signal attenuation and its resulting SNR degradation may limit bandwidth over a transmission medium.

[005] Thus, strong and stable signal production is needed for the proper operation of a communication device. In order to improve the power level of signals being transmitted over relatively long distances, and accordingly

to augment the transmission distance and/or data rate, devices may utilize power amplifiers to boost transmission signal strength. Power amplifiers, however, consumes considerable current from the supply source, and may create operational limitations for devices such as cell phones and other portable wireless devices relying on batteries for power supply. In addition, the power density of power devices limits the maximum transmitted power level at a given operation condition, as for instance, in base-stations of wireless systems. Therefore, there is a need for circuits, systems and methods for providing relatively strong and stable communication signals using components (e.g. power amplifiers) operating under efficient power usage conditions.

SUMMARY OF THE INVENTION

[006] According to some embodiments of the present invention, an output signal power amplifier within a communication device may be biased in response to a signal received by the device. The power amplified may be operated in a non-linear operating range and the output signal, prior to being applied to the amplifier, may be adaptively pre-distorted according to distortion characteristics of the power amplifier, which depend on the amplifier's operation bias point.

[007] According to further embodiments of the present invention, the output signal may be pre-distorted as a function of the power amplifier's known distortion characteristics at a given bias level. In some embodiments the present invention the pre-distortion function may be intended to produce an approximation to the inverse of the distortion resulting from the power amplifier being operated in a non-linear range.

[008] According to further embodiments of the present invention, the output signal may be pre-distorted as a function of a parameter of a data signal received by the device.

[009] According to yet other embodiments, the invention may include a circuit and method for correcting distortion characteristics of a transmit unit, resulting an increased power efficiency of the unit. The invention may also include a power efficiency control unit, adaptive pre-distortion function and compensation digital base-band unit(s) to align time, phase and amplitude of signals concurrently transmitted and received.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The subject matter regarded as the invention is particularly pointed out and distinctly claimed in the concluding portion of the specification. The invention, however, both as to organization and method of operation, together with objects, features, and advantages thereof, may best be understood by reference to the following detailed description when read with the accompanying drawings in which:

[0011] Fig. 1 shows a block diagram of a multi-mode wireless communication system within which the portions of the present invention may be applied;

[0012] Fig. 2 shows a block diagram of an exemplary radio transceiver including power efficiency and linearization enhancement features according to some embodiments of the present invention;

[0013] Fig. 3 shows a block diagram of a synchronization engine which may be used for the adaptation of coefficients relating to digital pre-distortion according to some embodiments of the present invention;

[0014] Fig. 4 shows a block diagram of an exemplary coefficient adaptation circuit coupled with a complex gain adjust circuit according to some embodiments of the present invention;

[0015] Fig. 5 shows a block diagram of an optimizer according to certain embodiments of the present invention, for example an optimizer based on the secant method;

[0016] Fig. 6 shows a block diagram of an exemplary power efficiency control unit which may be used to adjust a power level applied to a buck

regulator (DC-DC converter) according to some embodiments of the present invention; and

[0017] Fig. 7 shows a flowchart including exemplary steps of a method or adaptation algorithm according to some embodiments of the present invention.

[0018] It will be appreciated that for simplicity and clarity of illustration, elements shown in the figures have not necessarily been drawn to scale. For example, the dimensions of some of the elements may be exaggerated relative to other elements for clarity. Further, where considered appropriate, reference numerals may be repeated among the figures to indicate corresponding or analogous elements.

DETAILED DESCRIPTION

[0019] In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of the invention. However, it will be understood by those skilled in the art that the present invention may be practiced without these specific details. In other instances, well-known methods, procedures, components and circuits have not been described in detail so as not to obscure the present invention.

[0020] Unless specifically stated otherwise, as apparent from the following discussions, it is appreciated that throughout the specification discussions utilizing terms such as "processing", "computing", "calculating", "determining", or the like, refer to the action and/or processes of a computer or computing system, or similar electronic computing device, that manipulate and/or transform data represented as physical, such as electronic, quantities within the computing system's registers and/or memories into other data similarly represented as physical quantities within the computing system's memories, registers or other such information storage, transmission or display devices.

[0021] Embodiments of the present invention may include apparatuses for performing the operations herein. This apparatus may be specially constructed for the desired purposes, or it may comprise a general purpose computer selectively activated or reconfigured by a computer program stored in the computer. Such a computer program may be stored in a computer readable storage medium, such as, but is not limited

to, any type of disk including floppy disks, optical disks, CD-ROMs, magnetic-optical disks, read-only memories (ROMs), random access memories (RAMs) electrically programmable read-only memories (EPROMs), electrically erasable and programmable read only memories (EEPROMs), magnetic or optical cards, or any other type of media suitable for storing electronic instructions, and capable of being coupled to a computer system bus.

[0022] The processes and displays presented herein are not inherently related to any particular computer or other apparatus. Various general purpose systems may be used with programs in accordance with the teachings herein, or it may prove convenient to construct a more specialized apparatus to perform the desired method. The desired structure for a variety of these systems will appear from the description below. In addition, embodiments of the present invention are not described with reference to any particular programming language. It will be appreciated that a variety of programming languages may be used to implement the teachings of the inventions as described herein.

[0023] One of ordinary skill in the art should understand that the described invention may be used for all kinds of wireless or wire system, including but not limited to Tower Mounted Amplifier, wireless, wire, cables or fiber servers where a narrow interference has to be filtered out, phase linearity and filter parameters should be software programmable and when the interference may be in a channel.

[0024] According to some embodiments of the present invention, an output signal power amplifier within a communication device may be biased in response to a signal received by the device. The power amplified may be operated in a non-linear operating range and the output signal, prior to being applied to the amplifier, may be pre-distorted as a function of the amplifier's bias level.

[0025] According to further embodiments of the present invention, the applied signal to a non-linear structure (e.g., power amplifier) may be pre-distorted as a function of the power amplifier's known distortion characteristics at a given bias level. In some embodiments the present invention the pre-distortion function may be intended to produce an approximation to the inverse of the distortion characteristics resulting from the non-linear behavior of the power amplifier.

[0026] According to further embodiments of the present invention, the transmit signal prior to its application to a non-linear structure may be pre-distorted as a function of parameters of a data signal received by the device and of the properties of the envelope of the transmit signal.

[0027] Turning now to Fig. 1, there is shown a block diagram of a multi-mode wireless communication system which may utilize circuits, systems and methods relating to certain embodiments of the present invention. As illustrated, a multi-system transmitter or transceiver 100 may be used by one or more applications 200 to communicate with one or more wireless networks such as a wireless network (e.g. WiFi - 802.11a,b,g), a cellular network, or additional networks (e.g. GPS or Bluetooth).

[0028] Turning now to Fig. 2, there is shown a block diagram of an exemplary radio transceiver 100, including power efficiency and linearization enhancement features, according to some embodiments of the present invention. Visible from Fig. 2, is that a complex transmission signal to be transmitted by the transceiver may be monitored by a Power Efficiency Control Unit 102 ("PECU"), and the PECU 102 may produce one or more control signals (e.g ENPD and TX IQ_{AUX}) derived from either or both the complex transmission signal and from a signal being received by the transceiver 100.

[0029] A control signal produced by the PECU 102 (e.g. TX IQ_{AUX}) may directly or indirectly adjust a power amplifier 110 intended to deliver the transceiver's output signal power. According to some embodiments of the present invention, such as the one exemplified in Fig. 2, the control signal from the PECU 102 may adjust the bias point or level of the power amplifier 110 by means of several intermediary circuits. The control signal may pass through a detector ("DET") 104 to extract the contour (e.g. envelope detector) or the average value of the envelope (e.g. peak detector) of the DET 104 input signal, and the output of the DET 104 may be converted to an analog output by a Digital-to-Analog Converter 106 ("DAC"). Whereas the output of the DAC 106 may be used to drive a DC-to-DC converter 108 whose output may be used to provide a variable bias supply voltage to the power amplifier 110 correlated to the output signal at the output of the DAC 106. By adjusting the voltage level of the power

being supplied to the power amplifier 110, the amplifier's bias point or level may also be adjusted or modified.

[0030] According to some embodiments of the present invention, the control signal produced by the PECU 102 may be derived so as to set the bias point or level of the amplifier into a non-linear region of operation. It is known that an amplifier may be more efficient in its consumption of power when operating in a non-linear region. Various methods for operating amplifiers in a non-linear region, where their complex amplification factors (magnitude and phase) vary according to the level of signal, are well known and are usually performed in order to enhance power usage efficiency. Any non-linear elements presently known, for instance, an amplifier or any non-linear elements to be devised in the future are applicable to present invention.

[0031] In order to compensate for non-linear distortion which may occur to a signal passing through an amplifier biased to a point in a non-linear region of operation (i.e. being operated in a non-linear region), the signal to be amplifier may be pre-modified or pre-distorted prior to being applied to the amplifier. Pre-distortion of a signal being applied to an amplifier biased in a non-linear region may be of an inverse nature to the distortion introduced by the amplifier. Pre-distortion of a signal being applied to an amplifier operated in a non-linear region of operation is known, and any method presently known, or to be devised in the future, for pre-distortion of a signal to be applied to an amplifier biased to a non-linear operating region, may be applicable to the present intention. Turning briefly to Fig.

8, there are shown three graphs illustrating, from left to right, how signal pre-distortion may be used to at least partially compensate for distortions introduced by a non-linear element, such that the output of the non-linear device has characteristics similar to those of a linear amplifier.

[0032] Turning back to Fig. 2, Complex Gain Adjust ("CGA") unit 112 may perform a pre-distortion operation on a signal (e.g. TX IQ) to be amplifier by the amplifier 110. In the example shown in Fig. 2, the signal TX IQ may be a complex signal meant to transmit a symbol defined by a complex value having a real and imaginary component. The complex signal of Fig. 2 may thus have two components, I and Q, and each component may be separately adjusted by the CGA 112. The CGA 112 may receive the signal to be amplified in the form of a digital data stream and may adjust values in the digital data stream partially based on adaptation or pre-distortion coefficients stored in a look-up table 132.

[0033] Given that an amplifier's distortion characteristics may be different for each bias point or level to which it is set, different pre-distortion or signal adaptation coefficients may be needed to counteract the amplifier's distortions when operated in its non-linear region. The pre-distortion or signal adaptation coefficients used by the CGA 112 may be partially based, or a function of, the bias point or level to which the amplifier 110 is set by the PECU 102. According to some embodiments of the present invention, the PECU 102 may provide a control signal to the amplifier 110, setting the amplifier 110 to a specific bias point or level, and may provide a corresponding control signal to the CGA 112, instructing the CGA 112

which pre-distortion or signal adaptation coefficients to use in order to counteract the amplifier's 110 distortion characteristics at its current bias point or level.

[0034] According to some embodiments of the present invention, the PECU 102 may provide a different control signal to the 110 for each separate communication device with which the transceiver 100 is communicating, and may even provide a different control signal for the same communication device if transmission conditions change during a communication session. Accordingly, if the PECU 102 causes the bias point or level of the amplifier 110 to change, the PECU 102 may provide the CGA 112 a signal instructing the CGA 112 to change which pre-distortion coefficients to use for compensating amplifier 110 distortions.

[0035] Once the CGA 112 has adapted or pre-distorted a signal, the signal may be converted from a digital data stream into an analog signal by one or more Digital-to-Analog Converters ("DAC"). Since in the example of Fig 2, the signal may have two components, the real and the complex components of the data streams, each data stream, representing the real and the imaginary components of the complex signal, may be converted by a separate DAC, 114A and 114B. The analog output of each of the DAC's, 114A & 114B, may be applied to a Quadrature Amplitude Modulator 116 ("QAM"). Quadrature Amplitude Modulators are well known and any such modulator presently known or to be devised in the future is applicable to the present invention. However, it should be noted that the present invention is not limited to any specific type of modulator or

demodulator and may used with any such modulators presently known or to be devised in the future.

[0036] The TX Chain 118, between the output of the Modulator 116 and the input to the amplifier, 110 may include (a) a band-pass filter, (b) variable and fixed gain amplifiers and (c) frequency converter units and (d) control functions. The signal at the output of the TX Chain 116 may reside in the frequency band of the network (WiFi, CDMA, WCDMA, etc.). One purpose of the TX Chain 118 is to provide the signal at the input of the power amplifier 110 at the desired frequency of operation and power level as defined according to the operation of the network or device with which the transceiver 100 is to communicate.

[0037] According to some embodiments of the present invention, the PECU 102 may receive an input signal or feedback from the output side of the amplifier 110. Feedback may include a signal provided from a peak detector 126 monitoring power of the transmitted signals of the transceiver 100, where the peak detector 126 may provide a signal to the PECU either directly or through an Analog-to-Digital Converter 128 ("ADC"). According to some embodiments of the present invention, the ADC 128 may sample an analog output of the peak detector 126 and may convert the analog output to a data stream the PECU 102 may receive and interpret.

[0038] According to further embodiments of the present invention, further feedback may be provided though a signal which is coupled to the output signal of the amplifier 110. A coupling element 111 may be used to

extract an analog sample of the signal of the amplifier 110 output signal and to direct the analog sample of the signal through an RX chain 120 which may include (1) a band-pass filter, (2) low pass filters, variable gain amplifier, (3) frequency converter units (4) control functions, etc. If the received signal has been modulated by a QAM modulator, the received signal may be demodulated by a QAM demodulator 122, as shown in Fig. 2. , and both the I and Q components of the signal may be sampled by ADCs, 124A and 124B.

[0039] Although the transceiver of Fig. 2 shows QAM modulators and demodulators being used, one of ordinary skill in the art should recognize that the present invention may be practiced with any set of modulators and demodulators and sampling schemes, known today or to be devised in the future. Furthermore, although the RX chain 120 in Fig. 2 is connected with a complete demodulator 122, and may be used for both analog sample of the signal based calibration of signal (TX IQ) pre-distortion, and for receiving signals from other devices, it should be clear to one of ordinary skill in the art that various other RX chains and analog sample of the signal analysis circuits may be applicable to present invention. The present invention may include a variety of RX chains and/or amplifier 110 output signal feedback circuits which may be used for calibration of signal (TX IQ) pre-distortion, but which may not be suitable for receiving signals from other devices. Although not explicitly indicated in Fig. 2, the complete demodulator 122 may include (1) low pass and band

pass filters, (2) variable gain amplifiers, (3) equalizers, (4) frequency converters, etc.

[0040] The received and digitized signal may be passed along to any application for which the data is relevant and the received data may also be used by a digital base-band processing unit ("DBPU") 134 and a coefficient adaptation unit 130 in order to update pre-distortion coefficients stored in the look-up table 132 and used by the CGA 112.

[0041] According to some embodiments of the present inventions, the DBPU 134 may provide the PECU 102 information relating to various characteristics of the amplifier 110 output signal, including "Crest Factor" and "Adjacent Channel Power Ratio." This information may be used by the PECU 102 to determine a proper bias point or level for the amplifier 110. Should either the Crest Factor or Adjacent Channel Power Ratio values pass a predefined threshold for a specific network or device to which the transceiver 100 is transmitting, the PECU 102 may adjust the bias level of the amplifier 110 to reduce or stop distortions and may consequently cause the CGA 112 to either reduce or stop the corresponding pre-distortion being performed.

[0042] According to some embodiments of the present inventions, the DBPU 134 may provide the coefficient adaptation unit 130 information required in order to calculate or adapt pre-distortion coefficients used by the CGA 112 for pre-distortion at a given bias level or point. The DBPU 134 may provide the coefficient adaptation unit 130 with information relating to: (1) signal gain across portions of the transceiver 100, including

the amplifier 110; (2) time delay of the signal across portions of the transceiver 100, including the amplifier 110; and (3) phase shift of the signal across portions of the transceiver 100, including the amplifier 110.

[0043] According to some embodiments of the present invention, an output signal from the Digital Base-band Processing Unit 134 ("DBPU") indicating transmitted power (TX_{pwr}) may pass through a square root operation block 136, and the output of the square root operation block 136 may be gated with a signal from the PECU 102, i.e. EN PD, enabling pre-distortion by the CGA 112. According to the embodiment of present invention shown in Fig. 2, pre-distortion coefficients stored in the look-up table 132 may be indexed by values associated with the square root of the transmitted power (TX_{pwr}).

[0044] According to some embodiments of the present invention, the PECU 102 may set the amplifier 110 to operate in a non-linear operating region by setting the amplifier's bias point or level. The selection of a bias level may be made and changed based on signal power requirements of the network or device with which the transceiver 100 is communicating. Once a bias point or level is selected, a feedback or mirror signal may be analyzed by the DBPU 134 and coefficient adaptation unit 130 in order to calculate or adapt pre-distortion coefficients which may be used to compensate for the amplifier's 100 non-linearity. The calculated coefficients may be uploaded to a look-up table 132 and may be indexed based on either signal output power (TX_{pwr}), or on some function thereof, for example the square root of the output power (TX_{pwr}).

[0045] Various pre-distortion techniques and methodologies for calculating pre-distortion coefficients to compensate for non-linear amplification are known. Some examples of such methods may be found in each of the below listed publicly available references, and are hereby by reference incorporated into this application:

US 6449466 B1, "Adaptive digital pre-distortion correction circuit for use in a transmitter in digital communication system and method of operation" Sep. 10, 2002

J.K. Caves, "Amplifier Linearization Using a Digital Predistorter with fast Adaptation and Low Memory Requirements", IEEE on Vehicular technology, Vol. 39, no.4, pp.374-382, November 1990.

S. Mann et al. "Increasing Talk Time of Mobile radios with Efficient Linear Transmitter Architectures", Electronics & Communication Engineering Journal, pp. 65-76, April 2001.

[0046] During operation, the CGA 112 may modify the complex transmit signal TXIQ by the pre-distortion function which its complex output value depends on the stored coefficients in the look-up table 132 and the square root of the transmit power (TX_{pwr}) in "real-time,". The look-up table 132 may select the coefficients of the pre-distortion function applied to the CGA 112 based on a signal from the DBPU 134 indicating the present signal output power (TX_{pwr}). Should the DBPU 134 indicate to the PECU 102 that certain parameters (e.g. ACPR and CF) of the amplifier 110 output signal either exceed or are below specific limits, the PECU 102 may adjust the bias level of the amplifier 110 and/or the pre-distortion function According to certain embodiments of the present invention, each time the bias level of the amplifier 110 is changed, the pre-distortion coefficients may be either recalculated or adjusted. According to other

embodiments of the present invention, coefficients are calculated for a plurality of various bias levels each time the power efficiency calibration of the transceiver 100 is required and the coefficients are stored in the look-up for as long as the behavior of the non-linear element does not change.

[0047] Turning now to Fig. 3, there is shown a block diagram of a synchronization engine or baseband processing unit 134 which may be used for the synchronization and alignment of the transmitted and received samples for calibrating the digital pre-distortion and for the measurement of system parameters according to some embodiments of the present invention. According to the embodiment shown in Fig. 3, there may be two major tracking loops, a carrier phase and a delay lock loop. The carrier phase loop may include a complex modulator (CPXM), low pass filters and down sampling, a multiplier, a integrator, a dump block and a phase detector, which may remove phase shifts introduced by the signal path phase. When locked, the phase of the numerical control oscillator (NCO) may equal to the total phase shift introduced in the signal path. As a result, the samples transmitted in the real and imaginary channels appears, TXIQ, may be aligned with the received samples RXI and RXQ.

[0048] The delay locked loop may include complex correlators, an early-minus-late discriminator and a low pass filter, which may provide time alignment between samples. When the carrier phase and the delay locked loops are locked, both the complex transmitted and received

samples may be aligned. Signal gain may be compensated by comparing the levels of the transmitted and received signals.

[0049] In addition to the synchronization of the transmitted and received samples, the digital baseband unit 134 may provide measurement of the power level at the adjacent channel to determine the adjacent channel power ratio The second numerical controlled oscillator (NCO) may demodulate the adjacent channel. The power of the demodulated signal may be measured and the value compared against the power of the principal channel. The ACPR, adjacent channel power ratio, indicator may turn on when the value raises above a certain threshold. The other information extracted from the digital baseband 134 refers to the peak to average ratio or crest factor (CF). The CF may be measured at the digital baseband and the information may be used to control the power efficiency control unit 102

[0050] Turning now to Fig. 4, there is shown a block diagram of an exemplary coefficient adaptation circuit coupled with a complex gain adjust circuit and coefficient adaptation procedure according to some embodiments of the present invention. Once transmitted and received samples are synchronized, i.e., time, phase and gain are compensated, the coefficient adaptation block 130 may determine the coefficients of the pre-distortion function to be applied to the complex gain adjust block 112. The complex gain adjust may multiply the transmit signal by a distortion function. The values of the coefficients at different supply voltage, after their estimations, may be stored in a look-up table 132. The look-up table

132 may be indexed with the square root of the power (the magnitude) of the transmitted signal. The output of look-up table 132 may be a complex non-linear function, the distortion function, where the output varies according to the magnitude of the transmit signal.

[0051] Turning now to Fig. 5, there is shown an optimization block based on the method of Secants which may be used with the coefficient adaptation block of Fig. 4. Although the coefficient adaptation block shown in Fig. 4 may use a Secant based optimization based method, any other optimization method can be used in the present invention. The input signal at the input of the optimizer may be an error function, and the optimization block of Fig. 4 may minimize the error function. The output of the optimization block may be the coefficients of the distortion function.

[0052] Turning now to Fig. 6, there is shown the block diagram of a power efficiency control unit 102 according to some embodiments of the present invention. The PECU 102 may operate in accordance with the step 1000 through 12000 of the method illustrated in Fig. 7 and may generate an auxiliary TX ($TXIQ_{AUX}$) signal to control the supply voltage of the non-linear element 110, e.g. power amplifier, and may provide information to enable and disable the digital pre-distortion according to the properties of the transmitted signal. $TXIQ_{AUX}$ may depend on the received power level and ACPR. The output power may be constantly measured with the peak-detector and the information may be used to set the supply voltage of the power amplifier such as the amplifier operates at the non-linear region where high efficiency levels may be obtained. ACPR information may be

used to avoid excessive adjacent channel re-growth and the failure to meet the communication standard requirements. For transmit signal with complex modulation schemes and with excessive high crest factor, CF, entailing significant back-off of the non-linear element as the power amplifier, the CF may be used to enable and disable the distortion function as the non-linear element is forced to operate in the linear regime.

[0053] While certain features of the invention have been illustrated and described herein, many modifications, substitutions, changes, and equivalents will now occur to those skilled in the art. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention.